CERN Proton Driver (SPL)

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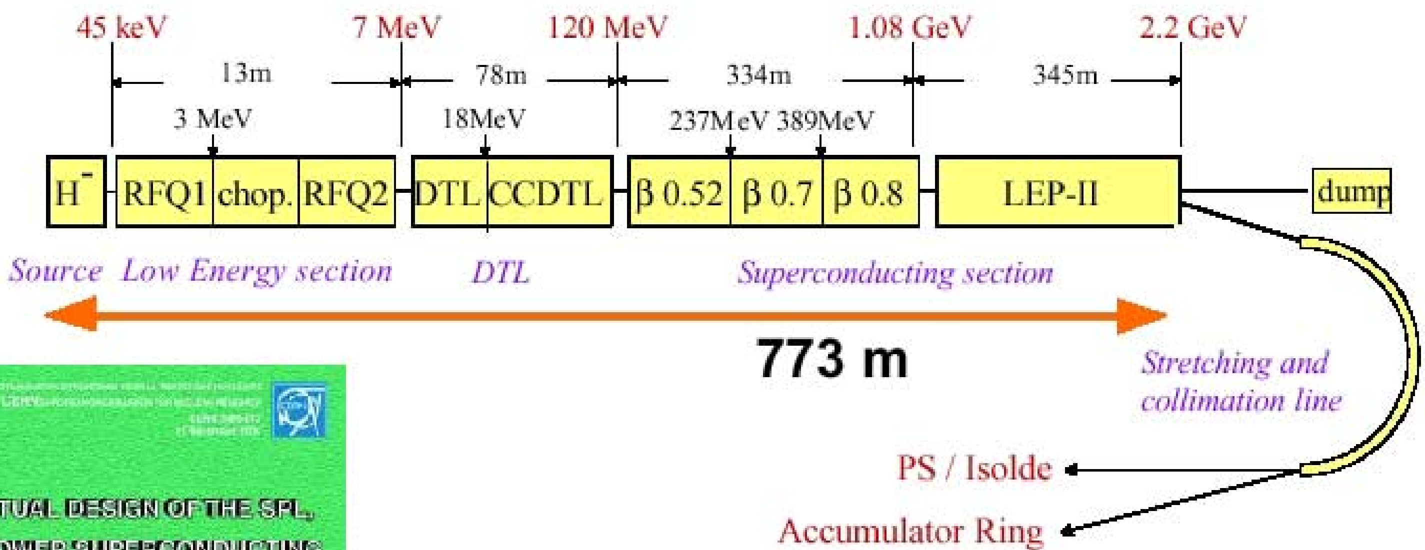
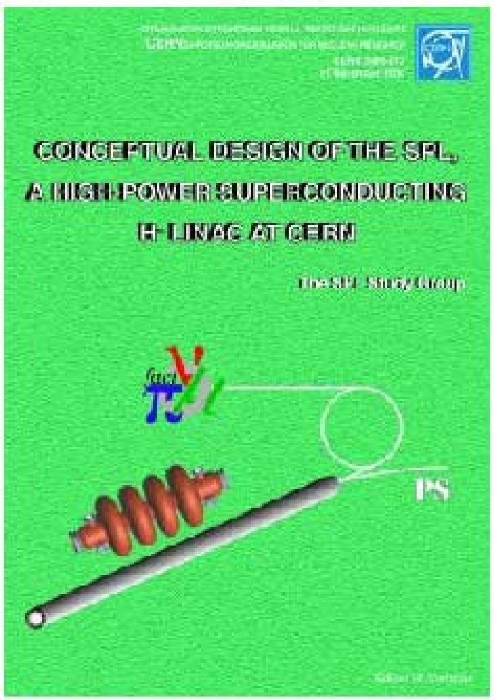
for the
SPL Working Group

Snowmass 2001

Basic lay-out of the SPL





CERN 2000-012

Basic Parameters:

Energy	2.2 GeV
Mean current	11 mA
Repetition rate	75 Hz
Beam Power	4 MW

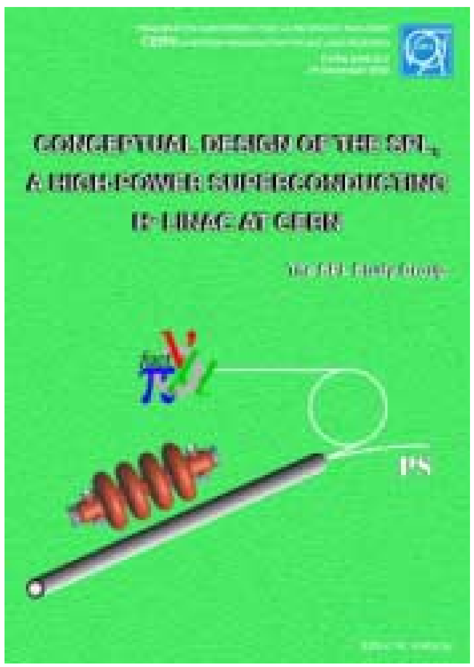
Applications of the SPL

- **Approved physics experiments**
  - **CERN Neutrinos to Gran Sasso (CNGS)**
  - **Anti-proton Decelerator**
  - **Neutrons Time Of Flight (TOF) experiments**
  - **ISOLDE**
  - **LHC**
- **Future potential users**
  - **“Conventional” neutrino beam from the SPL “super-beam”**
  - **Second generation ISOLDE facility (“EURISOL” -like)**
  - **Neutrino Factory**

Motivation

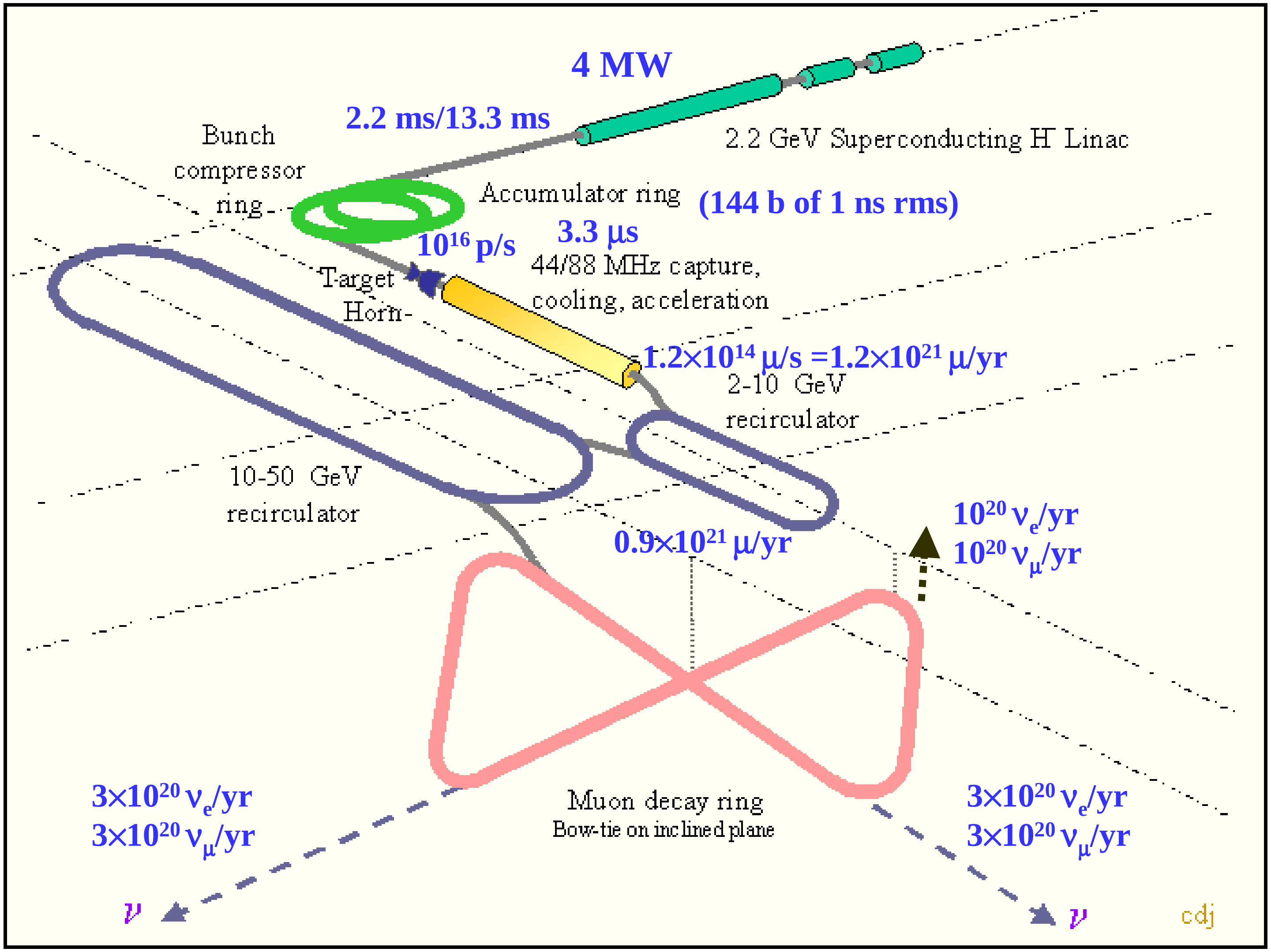
Strong incentive:

- to design and build a high power proton driver for a Neutrino Factory at a competitive cost (using the LEP RF equipment ?).
- to upgrade the proton beams provided by the PS Complex, improving the performance for planned uses and providing potential for new uses.

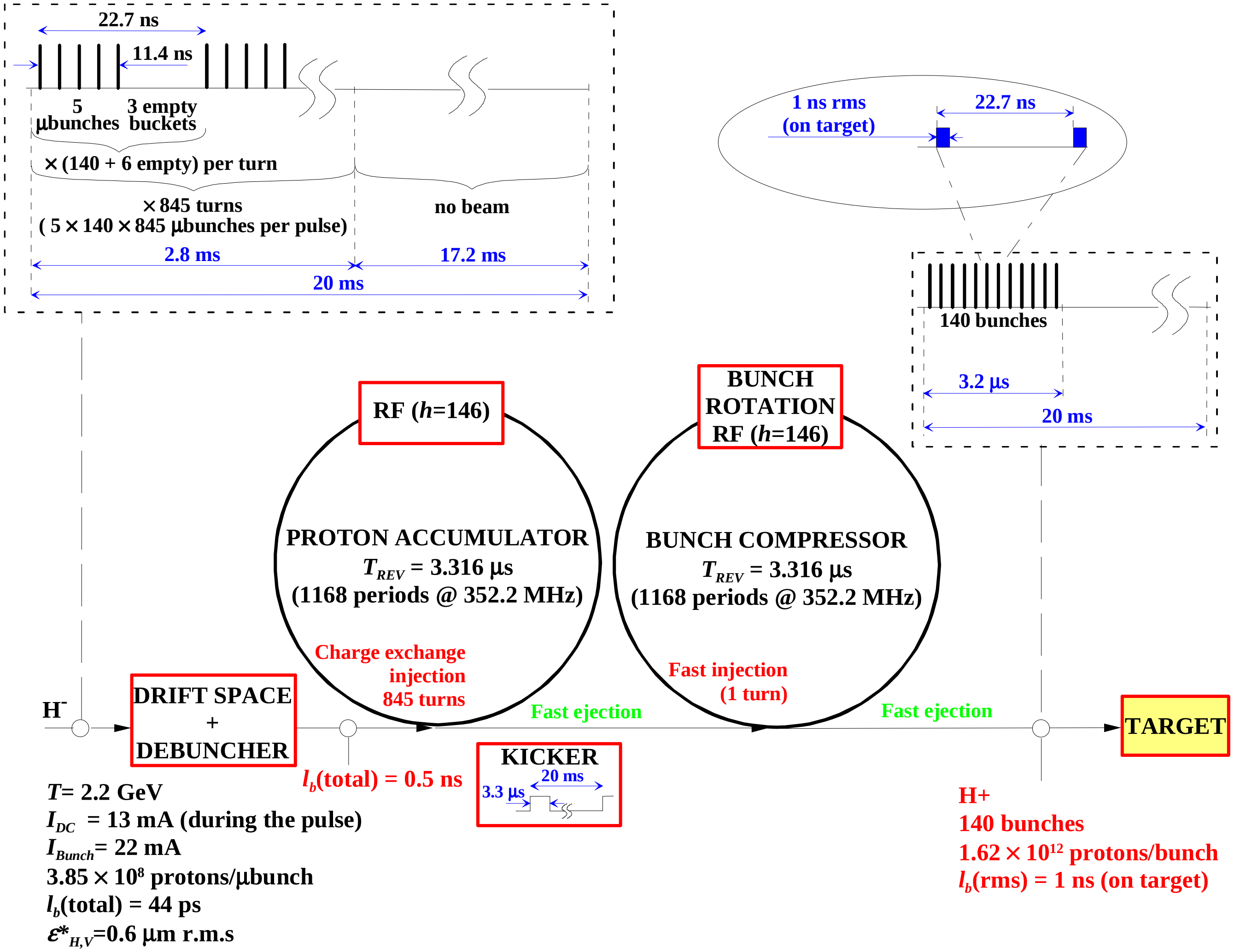


The LEP SC-RF system:
288 SC cavities in 72 cryostats
(812 meters!), 44 klystrons

CERN Reference Scheme for a Neutrino Factory



Accumulator-Compressor scheme

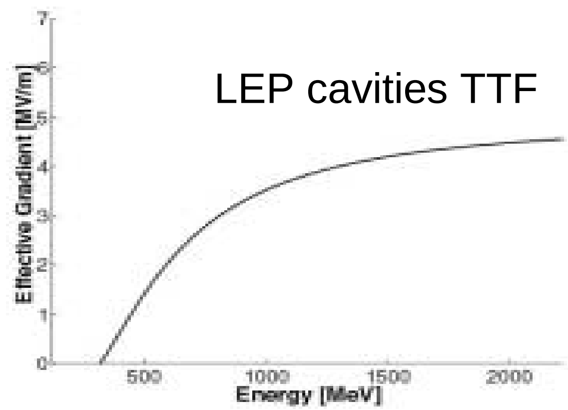


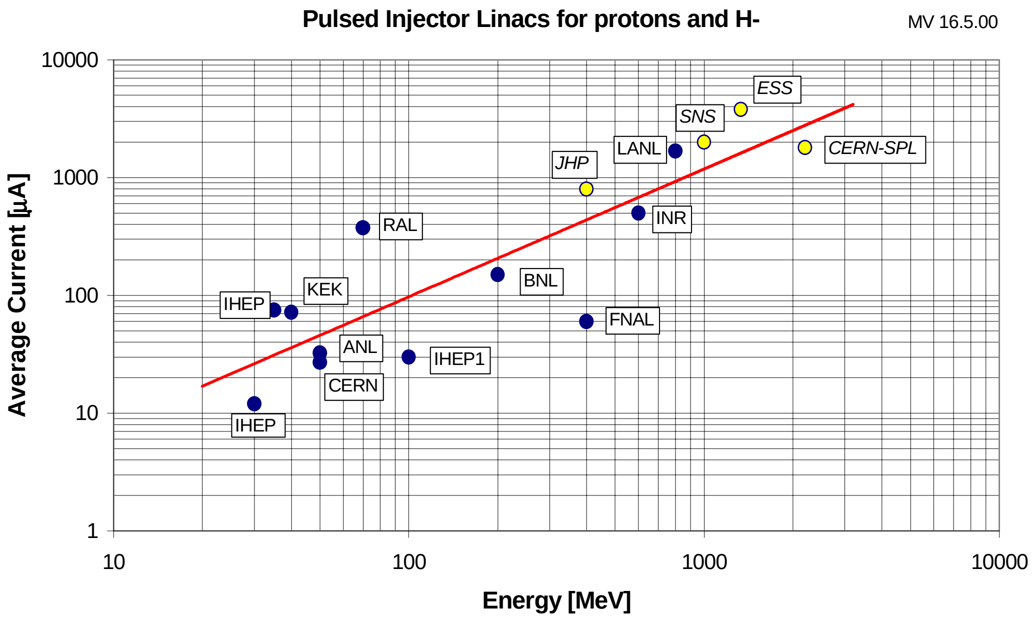
LEP SC cavity modules today...

Choice of Basic Parameters

2.2 GeV:

- LEP cavities (β=1) are efficient for W>1GeV
- Reduced space charge tune shift in the PS for injection energies > 1.4 GeV (present PSB)
- Efficient pion production for the Neutrino Factory for W > 2 GeV





75 Hz : for intense beams, a high rep. rate reduces charge per pulse (possible only with linacs!), limit given by power efficiency

11 mA : optimum distribution of klystrons, same current as LEP2

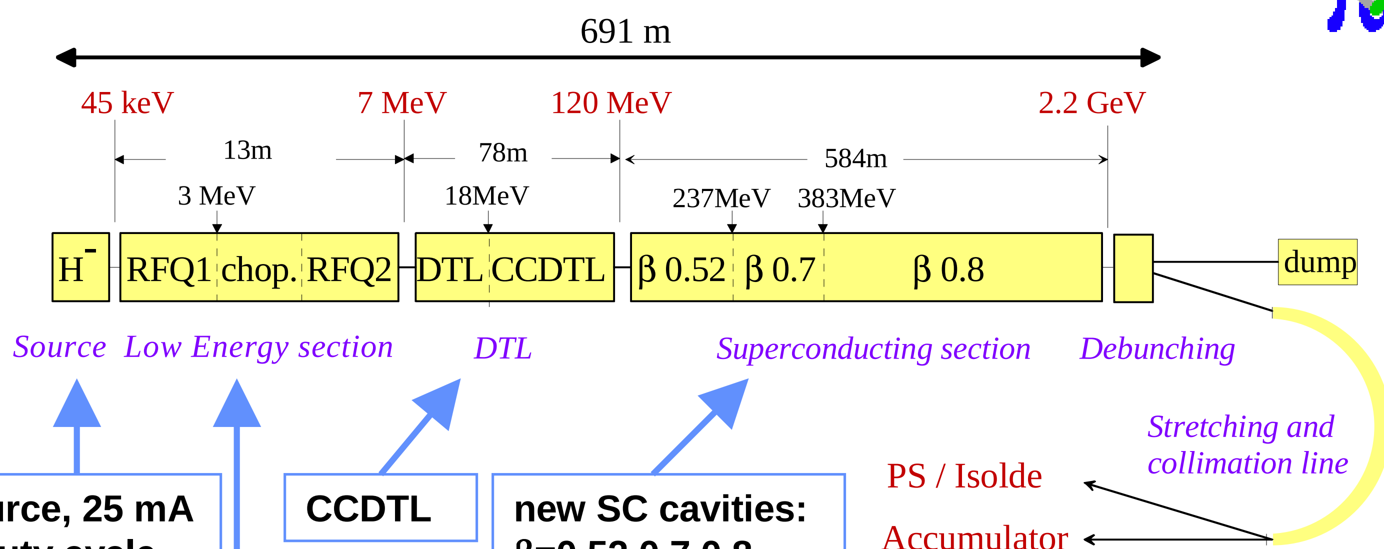
RF and Superconducting cavities Parameters

Section	design beta	Gradient [MeV/m]	N. of cells/cavity	Cryostat length [m]	Input Energy [MeV]	Output Energy [MeV]	N.of cavities	N.of cryostats	N.of tubes	RF Power [MW]	Length [m]
1	0.52	**3.5**	4	5.76	120	236	42	14	42 T	1.5	101
2	0.70	**5**	4	8.46	236	383	32	8	32 T	1.9	80
3	0.80	**9**	5	11.29	383	1111	52	13	13 K	9.5	166
4	**0.80**	**9**	**5**	**11.29**	**1111**	**2235**	**76**	**19**	**19 K**	**14.6**	**237**
TOTAL							**202**	**54**	**32 K + 74 T**	**27.9**	**584**

NOTES:

- distance between cryostats (for focusing doublets) is 1.49 m all along the linac
- sections 1 and 2: power tetrodes are preferred to help the operation of field regulation loops and improve beam stability
- sections 3 & 4: 4 cavities/klystron

Updated SPL block diagram



H- source, 25 mA
14% duty cycle

CCDTL

new SC cavities:
β=0.52,0.7,0.8

Fast chopper
(2 ns transition time)

RF system:
- **freq.: 352 MHz**
- **ampli.: tetrodes and LEP klystrons**

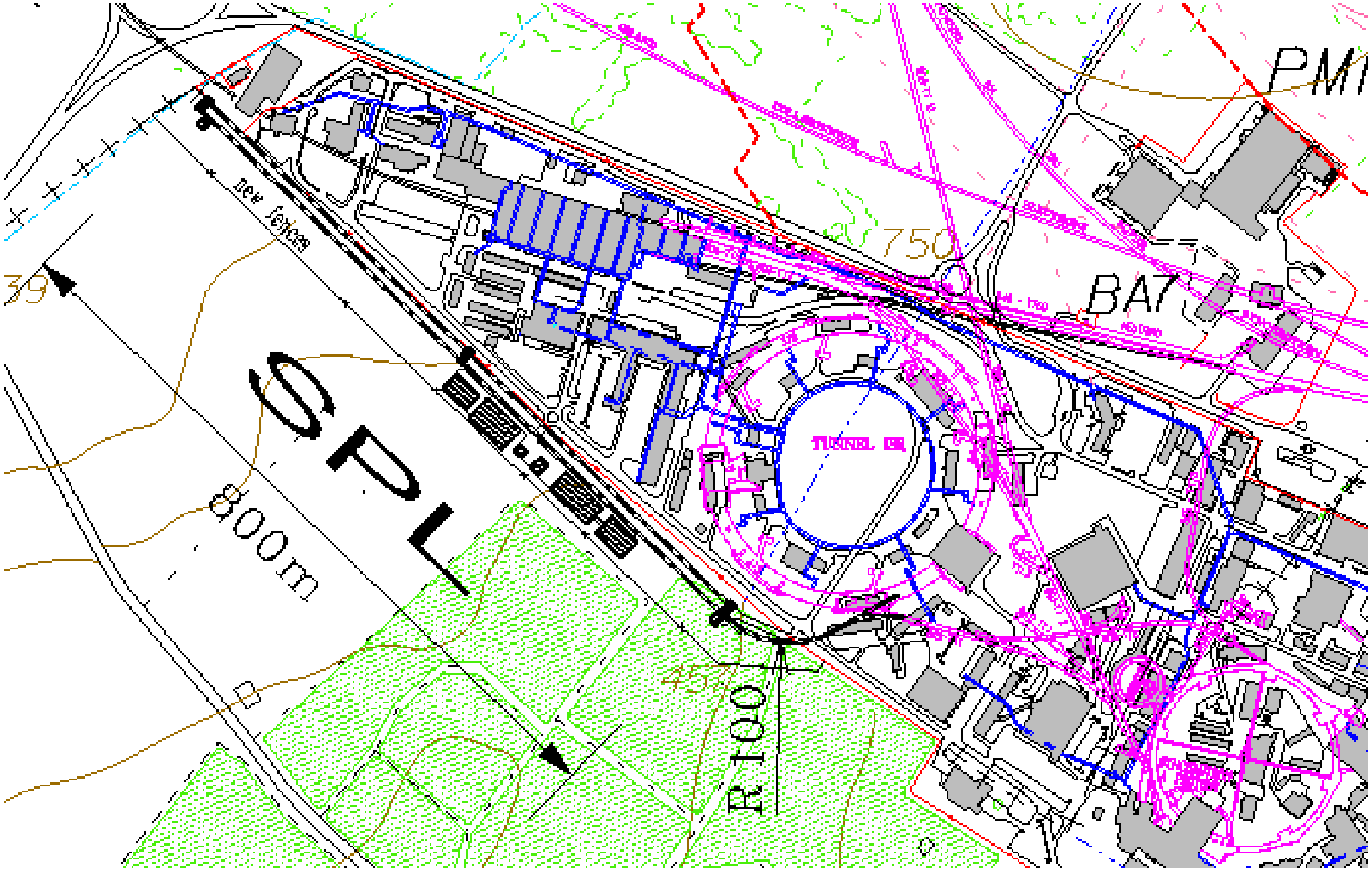
Section	Input energy (MeV)	Output energy (MeV)	No. of cavities	Peak RF power (MW)	No. of klystrons	No. of tetrodes	No. of Quads	Length (m)
Source, LEBT	-	0.045	-	-	-	-	?	3
RFQ1	0.045	3	1	0.4	1	-	-	3
Chopper line	3	3	5	0.3	-	5	12	6
RFQ2	3	7	1	0.5	1	-	-	4
DTL	7	120	100	8.7	11	-	160	78
β=0.52	120	236	42	1.5	-	42	28	101
β=0.7	236	383	32	1.9	-	32	16	80
β=0.8 I	383	1111	52	9.5	13	-	26	166
β=0.8 II	**1111**	**2235**	**76**	**14.6**	**19**	**-**	**19**	**237**
Debunching	**2235**	**2235**	**4**	**-**	**1**	**-**	**2**	**13**
Total			**313**	**37.4**	**46**	**79**	**263**	**691**

(focusing period of β=0.8 II is twice as long as for β=0.8 I → 19 quadrupoles less)

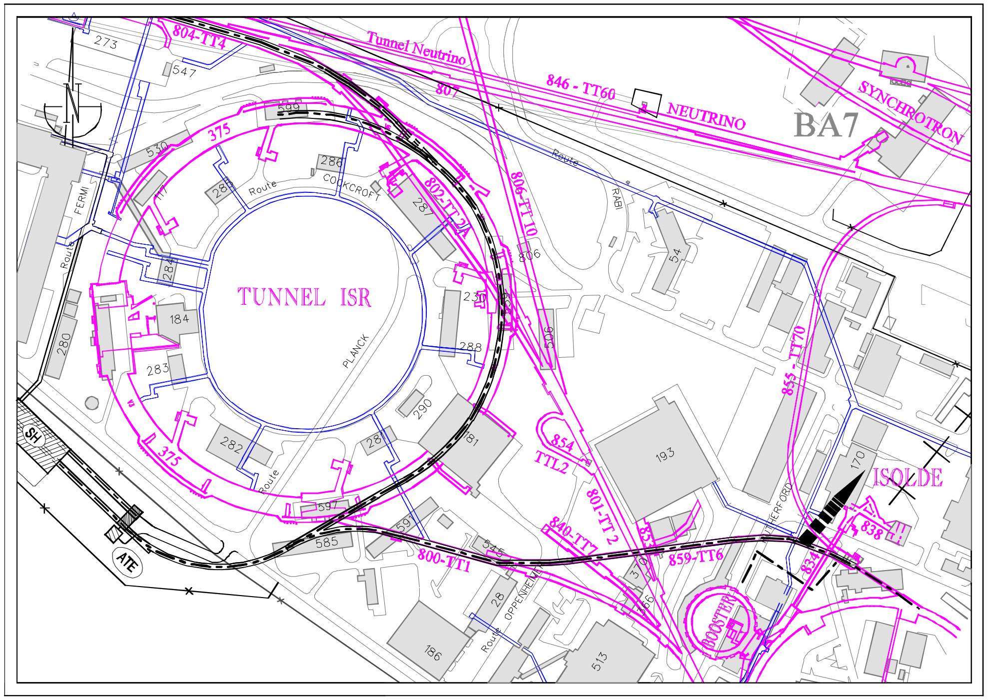
Improvements w.r.t. the reference design

- Improved transitions between sections ➔ better beam stability
- Doubled period length above 1.1 GeV ➔ save 25 doublets, 8m, 3 MCHF
- Improved error studies ➔ 100% beam radius < 20 mm, even for large error case (30 %) ➔ quad. radius reduced from 100 mm to 60 mm, (17rms) ➔ save 2 - 3 MCHF
- Reduced longitudinal emittance: 0.6 $\rightarrow$ 0.3 π°MeV ➔ improved design of the transfer line (drift length 230 $\rightarrow$ 175 m, bunch length 180 $\rightarrow$ 130 ps)
- Use of beta=0.8 cavities up to the highest energy ➔ shorter tunnel (- 100 m), less cavities per klystron, better control of mechanical resonances

Layout on the CERN site



Connections to ISR, PS & ISOLDE

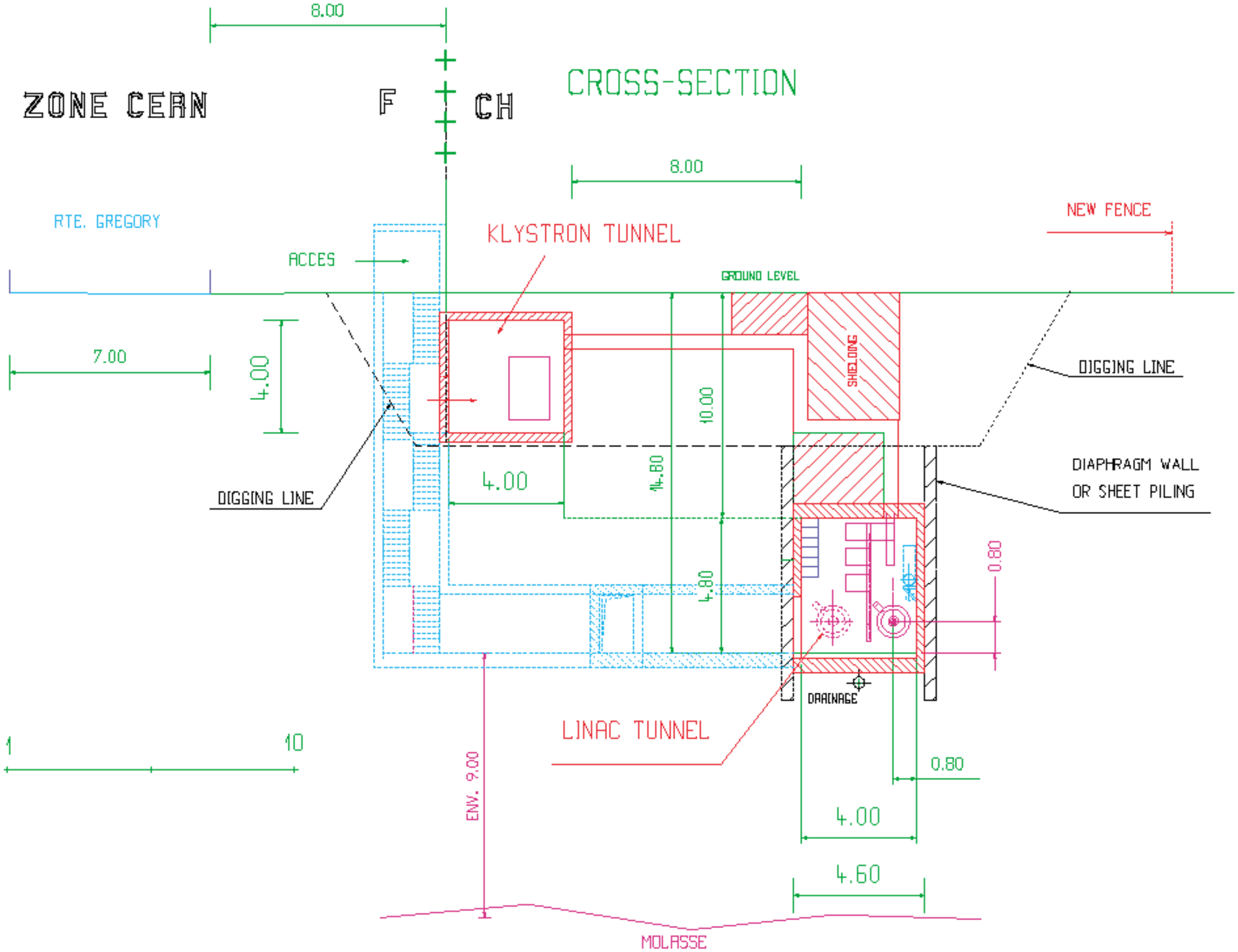


⇨ 2 bunching/debunching sections and 230m drift to increase beam length to 180 ps and to reduce energy jitter coming from SC cavity vibrations

⇨ only 100m of line before connecting to the existing tunnel network

⇨ easy connection to ISOLDE (old and new)

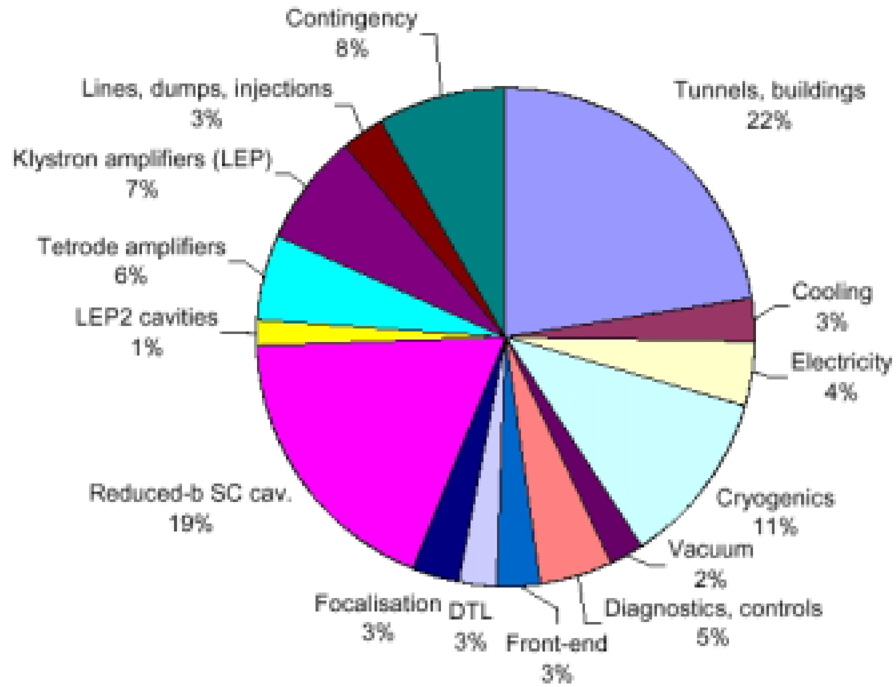
Cross section



Costing of the SPL

Note:
The costing exercise was done only for the SPL (does not include PDAC)

SPL Cost:
350 MCHF
(reference design)



Updated SPL beam specifications

	Parameter	Value	Unit
MEAN PARAMETERS	Ion species	H-	
	Kinetic energy	2.2	GeV
	Mean current during the pulse	13	mA
	Duty cycle [mean beam power]	14 [4]	% [MW]
	Pulse frequency	50	Hz
	Pulse duration [number of H- per pulse]	2.8 [2.27 E 14]	ms [H^-/pulse]
FINE TIME STRUCTURE	Bunch frequency [minimum distance between bunches]	352.2 [2.84]	MHz [ns]
	Duty cycle during the beam pulse [number of successive bunches/number of buckets]	61.6 [5/8]	%
	Number of bunches in the accumulator [total number of buckets – empty buckets]	140 [146-6]	
	Maximum bunch current [maximum number of charges per bunch]	22 [3.85 E 8]	mA [H^-/bunch]
BUNCH CHARACTERISTICS	Bunch length (total)	0.13	ns
	Energy spread (total) [relative momentum spread (total)]	1.2 [~ 0.42 E-3]	MeV
	Normalised horizontal emittance (1σ)	0.6	µm
	Normalised vertical emittance (1σ)	0.6	µm
	Energy jitter during the beam pulse	< +- 0.5	MeV
	Energy jitter between beam pulses	< +- 2	MeV

Revised parameters are in red

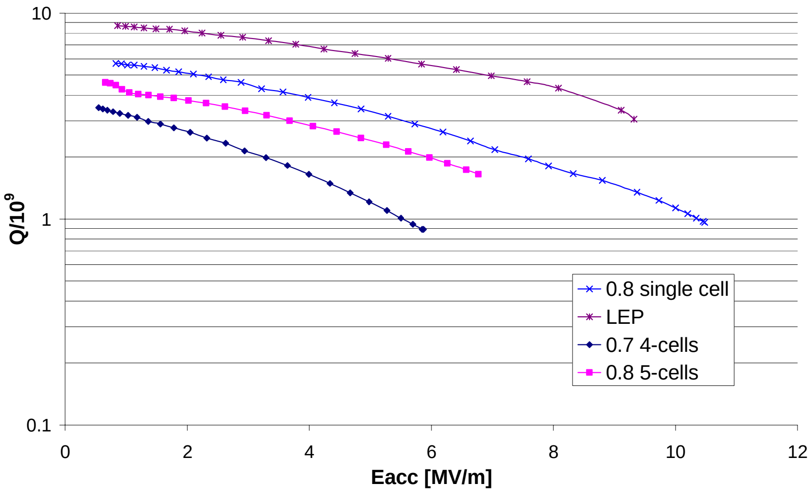
SPL: on-going activities

ITEM	ON-GOING WORK
H- source	Collective request for EC support …
Chopper	Re-design of 3 MeV beam-line and chopper structure to reduce requirements on the amplifier
RFQ(s)	MoU signed with CEA-IN2P3. No more news from Saclay & Legnaro
RT Linac structures	- DTL prototype delayed (IPN Grenoble) - Cold model of CCDTL structure in design at CERN - South Hall test place preparation delayed
SC cavities	- Pulsed test of multi-cell beta=0.8; problem of compatibility with LHC magnets tests in SM18… - Scaled model of single cell beta=0.52 in construction
Klystrons and power converters	Successful test of LEP klystron & power supply in pulsed mode at 50 Hz.
Tetrode amplifiers	Nothing done
Servo-systems for field regulation in SC cavities	LLRF workshop at Jefferson Lab (25-27/04/2001). Potential use of Los Alamos development for SNS, interest at CEA & IN2P3. Request for upgrade of Linac 2 & 3 with prototype hardware.
Beam dynamics	New SPL layout (100 m shorter – pulsing at 50 Hz)
Coordination with users – Specs. evolution.	- Neutrino Factory: change to 50 Hz rate - Plan for upgrade of high intensity proton beams at CERN: brainstorming going on. SPL front-end as an upgraded injector for the PSB… - ISOLDE / EURISOL: participation to meetings and workshops…

Superconducting cavities

The β=0.7 4-cell prototype

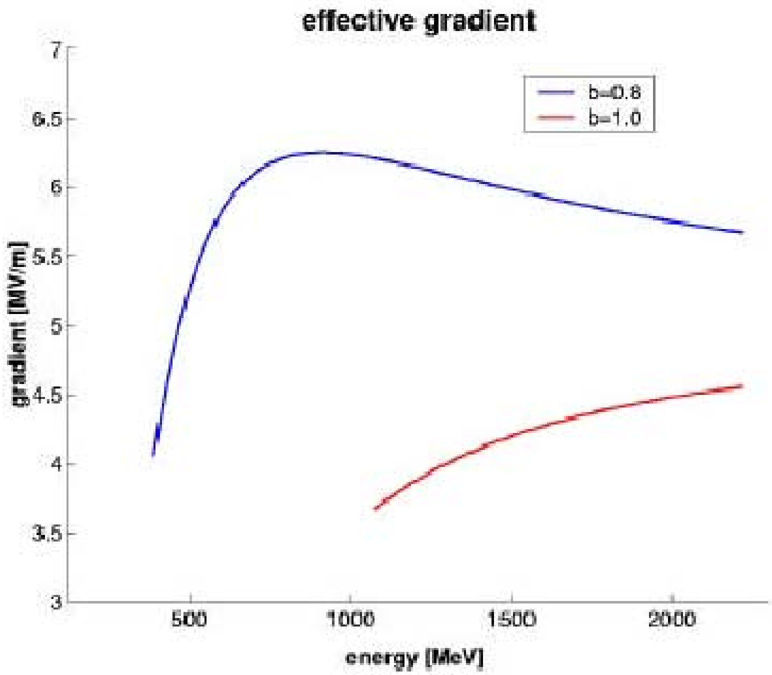
☆ CERN technique of Nb/Cu sputtering for β=0.7, β=0.8 cavities (352 MHz):
- ⇨ excellent thermal and mechanical stability
- ⇨ (very important for pulsed systems)
- ⇨ lower material cost, large apertures, released
- ⇨ tolerances, 4.5 °K operation with Q = 10^9



☆ Bulk Nb or mixed technique for β=0.52 (one 100 kW tetrode per cavity)

Question: what is the optimum energy to enter the LEP2 cavity section ?

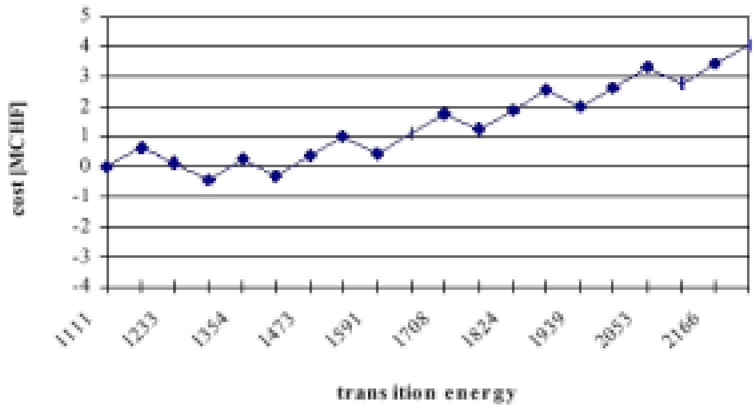
The answer depends on cost considerations...



β=0.8 cavities are more efficient than LEP cavities over all the energy range (higher gradient - 9 vs. 7.5 MV/m - and higher TTF)

- but they cost more money!

Implications of β=0.8 cavities used towards the end of the SPL



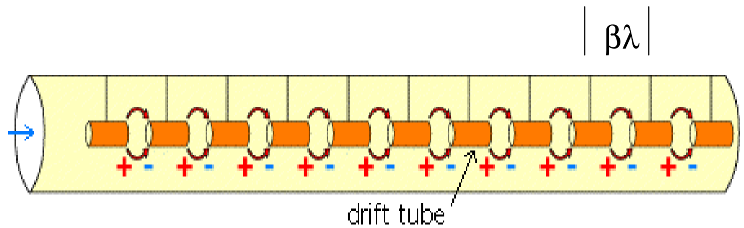
Cost includes:
civil engineering, vacuum, cavity costs, cryogenics (lower static losses, but higher dynamic losses, has to be optimized)

An SPL with the β=0.8 section up to full energy costs only 1% more *(in the background noise…)*, and has:

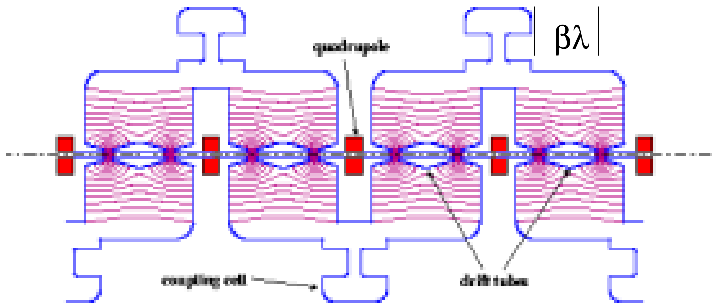
- 85 m shorter tunnel,
- only 3 types of SC cavities,
- easier 4 cavities/klystron layout
- easier control of mech. resonances
- same beam dynamics

(and remember that the β=0.8 are *reconditioned LEP cavities* we can still say that we re-use the LEP cavities!)

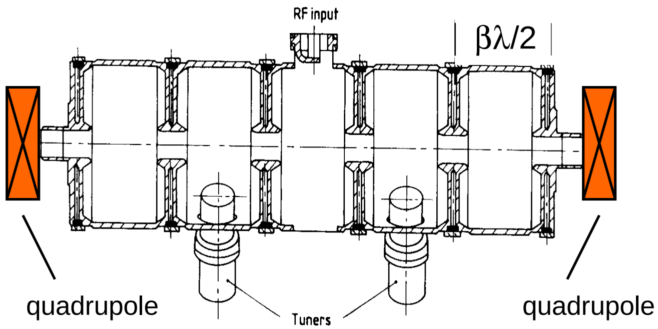
Study of RT structures for the SPL front-end



Alvarez Drift Tube Linac
unsurpassable <20 MeV
good but expensive for 20-120 MeV



Cell Coupled Drift Tube Linac
attractive solution for 20-150 MeV
(a cold model is being designed)

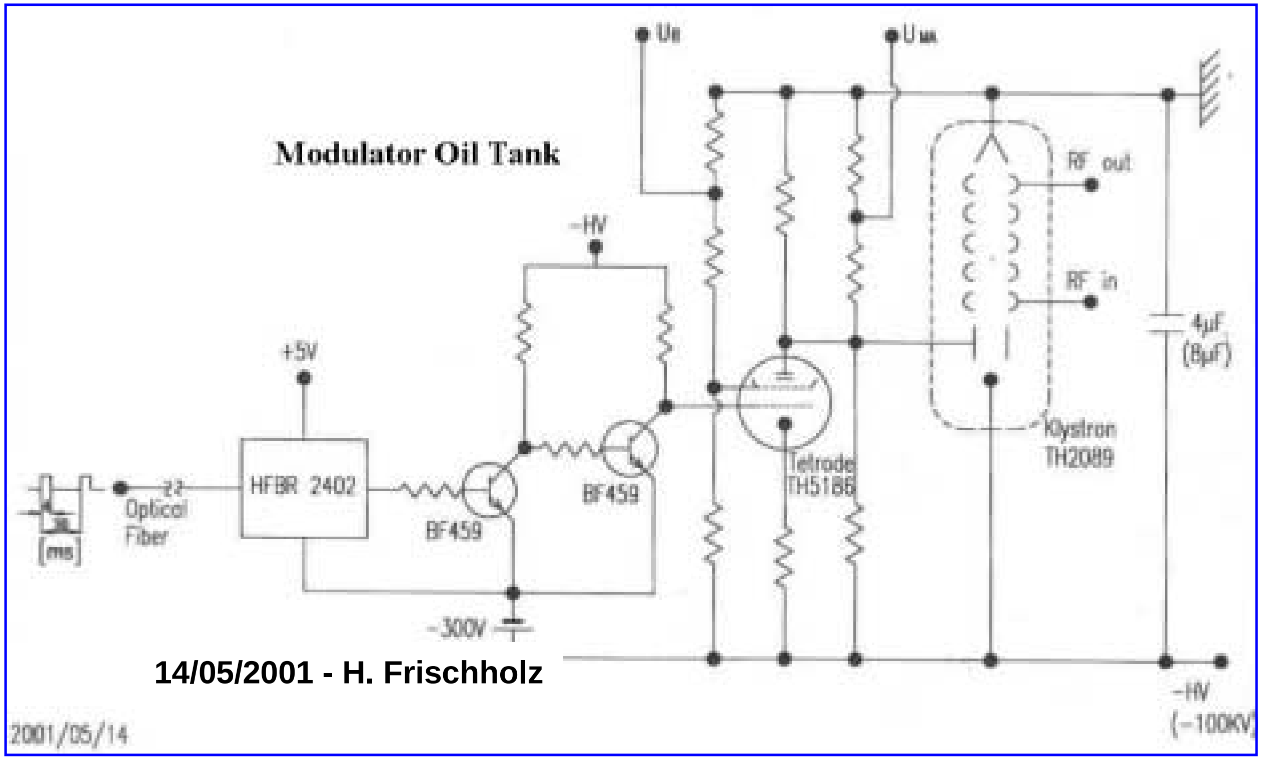


Coupled-Cell Cavity (LEP1)
better efficiency >110 MeV

The final choice will depend on preferred apertures, RT final energy, etc.

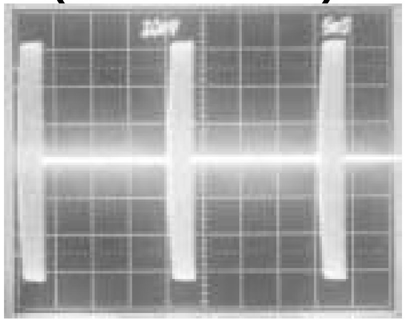
Pulsed operation of a LEP klystron set-up

Mod anode driver

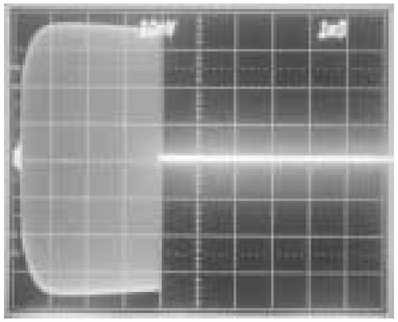


14/05/2001 - H. Frischholz

RF output power (800 kW max.)



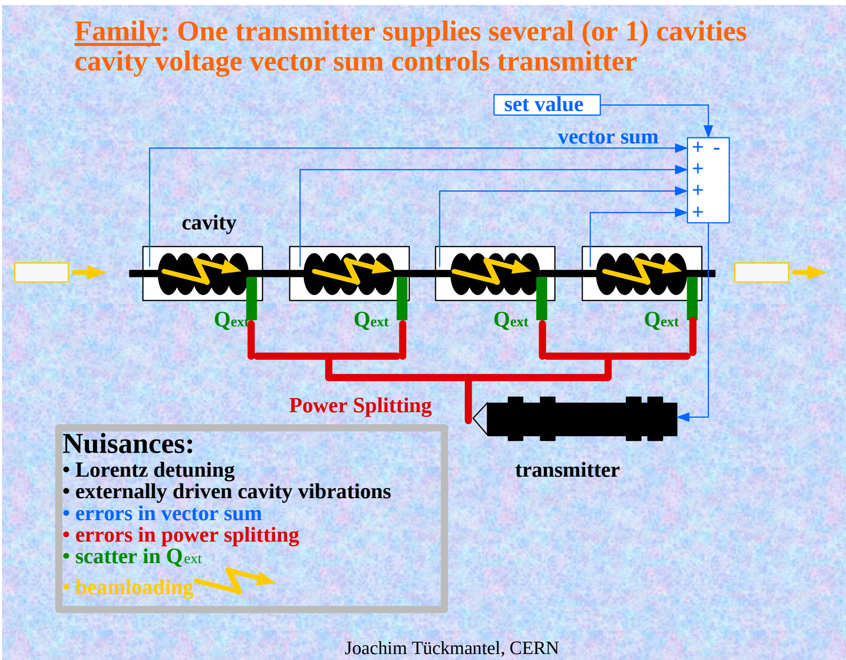
5 ms/div



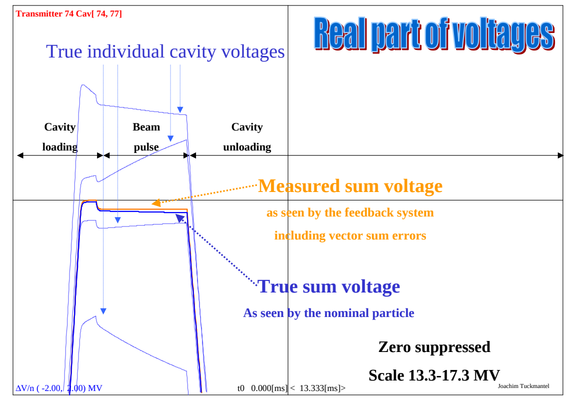
1 ms/div

⇒ **LEP power supplies and klystrons are capable to operate in pulsed mode after minor modifications**

RF power distribution & field regulation in the superconducting cavities

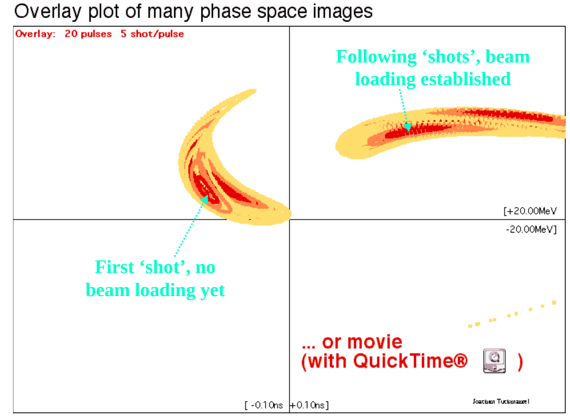


Effect on field regulation



Effect on the beam

Overlay plot of many phase space images

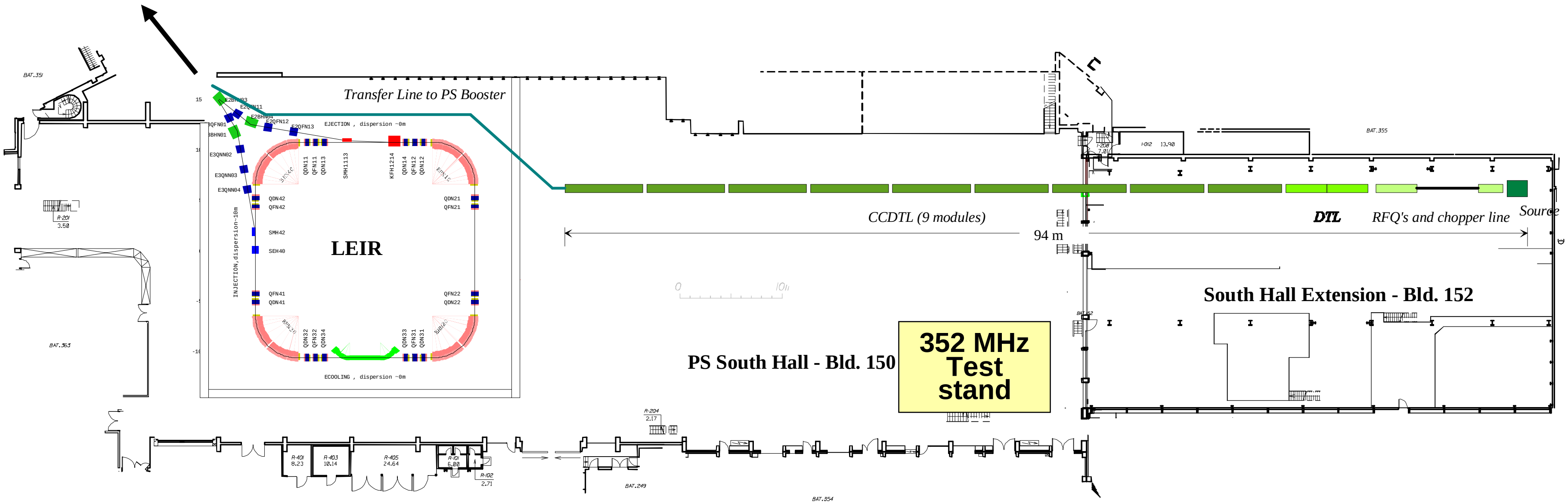


⇒ **unsolved problem ! Needs work**

⇒ **similar difficulties are likely in the muon accelerators...**

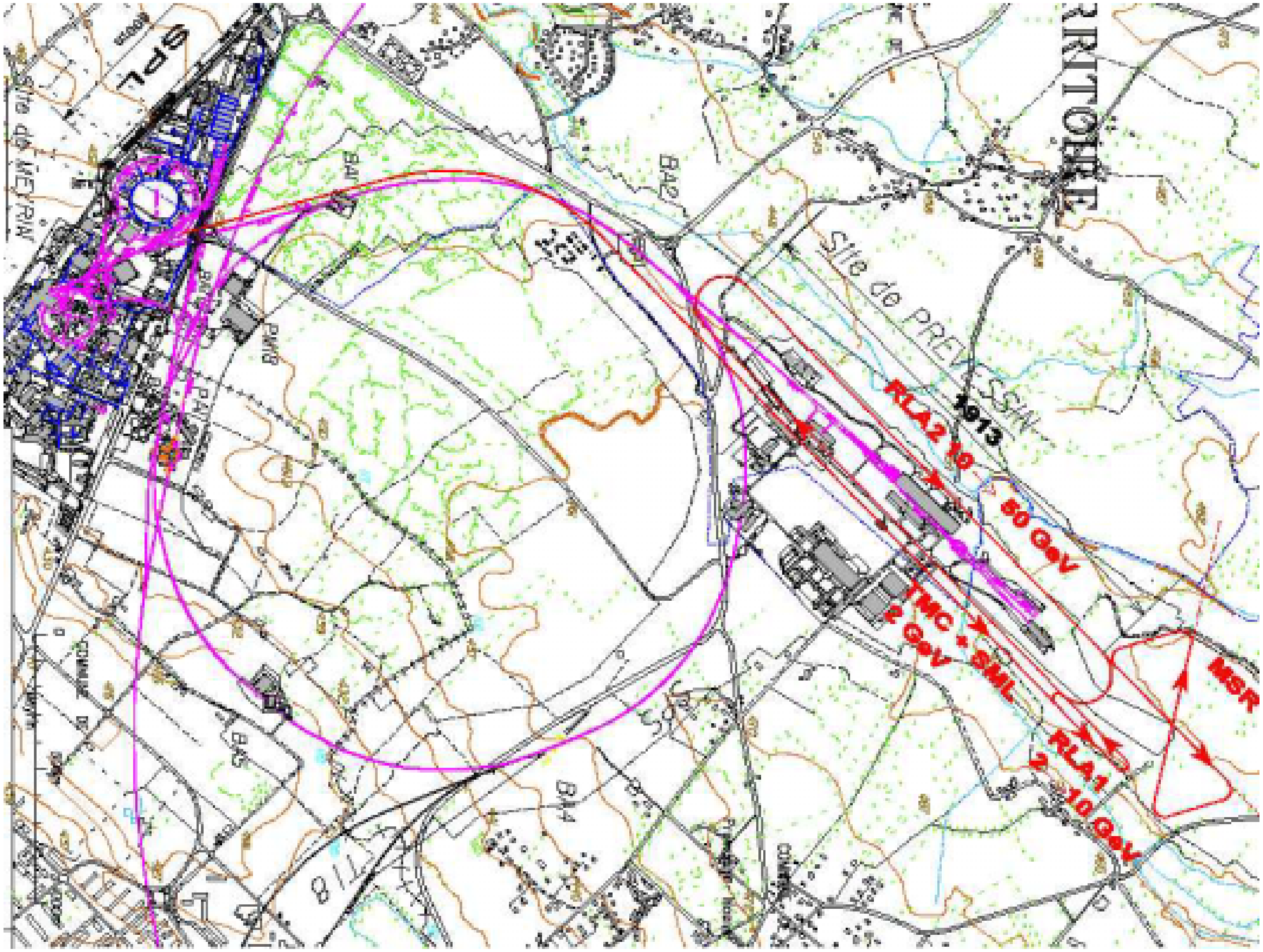
PS intensity increase program: possible location of the SPL front-end in the PS South Hall

To the PSB



⇒ × 1.8 the flux to CNGS (provided upgrades are made to PSB, PS & SPS…)
⇒ "cheap" installation, giving benefits from SPL related hardware before the full machine is operational & shortening the final setting-up

Several layouts for a Neutrino Factory at CERN are being studied



Conclusions

- Studies for a Neutrino Factory at CERN have seriously begun, thanks to the support of an enthusiastic physics community !
- The proton driver part, based on the SPL, is the mostly advanced item:
  - the existing LEP equipment makes it an economically valuable solution
  - the possibility to smoothly integrate the SPL in the CERN complex of accelerator is an attractive feature with short-term benefits
  - physics experiments are being proposed which take advantage of the SPL alone.
- Resources (manpower and money) are soon going to be the main problem :
  - world-wide collaboration among institutes is a must
  - priorities have to be defined between the various tasks and studies and resources distributed accordingly